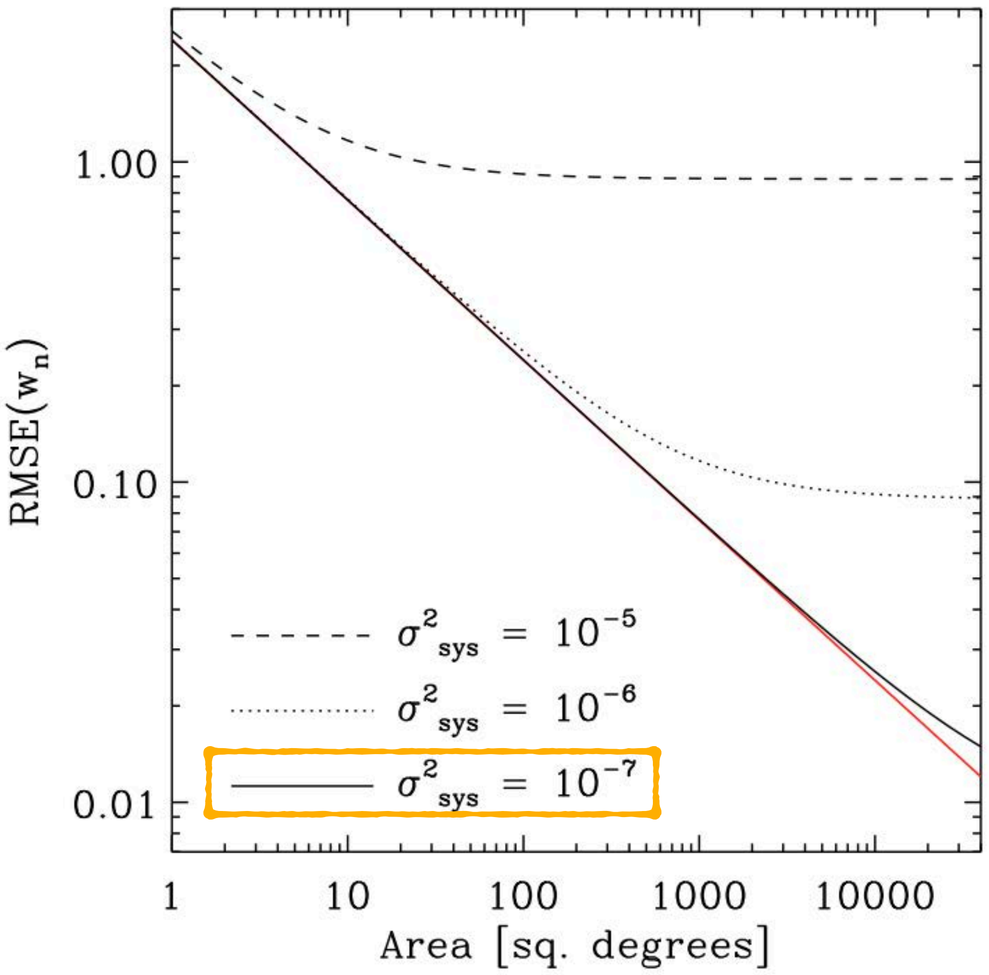
Measuring the shapes of billions of galaxies to one part in ten thousand

Chihway Chang (UChicago/KICP)

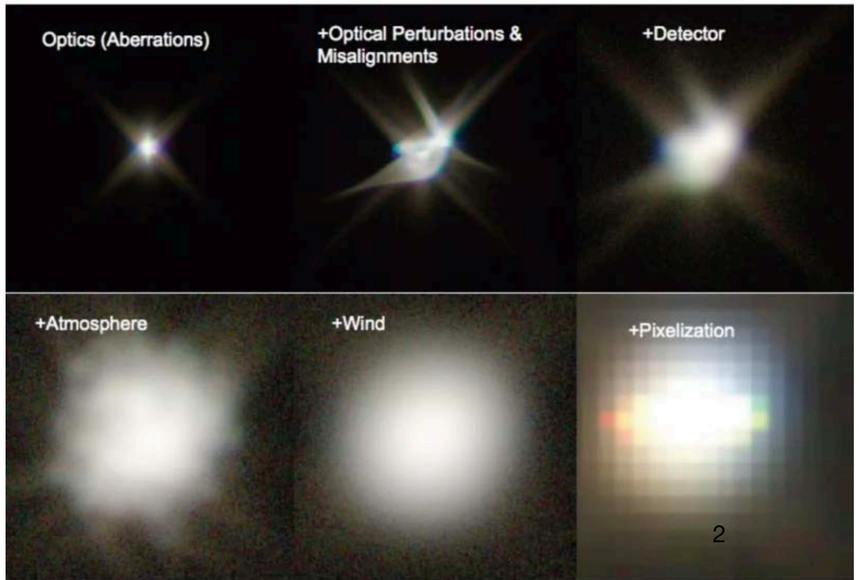
03-03-2023 Steve Kahn Symposium

Amara and Refrigier (2007)



It is quite shocking one day you wake up and realize that you are “senior” and how much has happened…

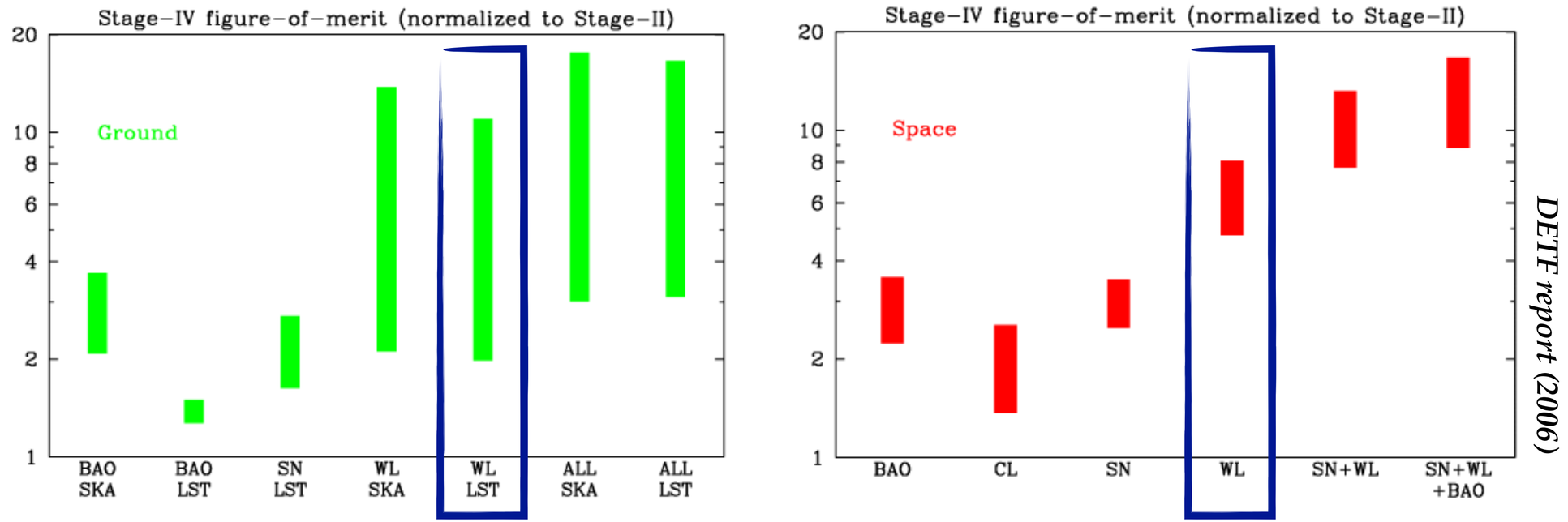
Ok enough about me, back to science!



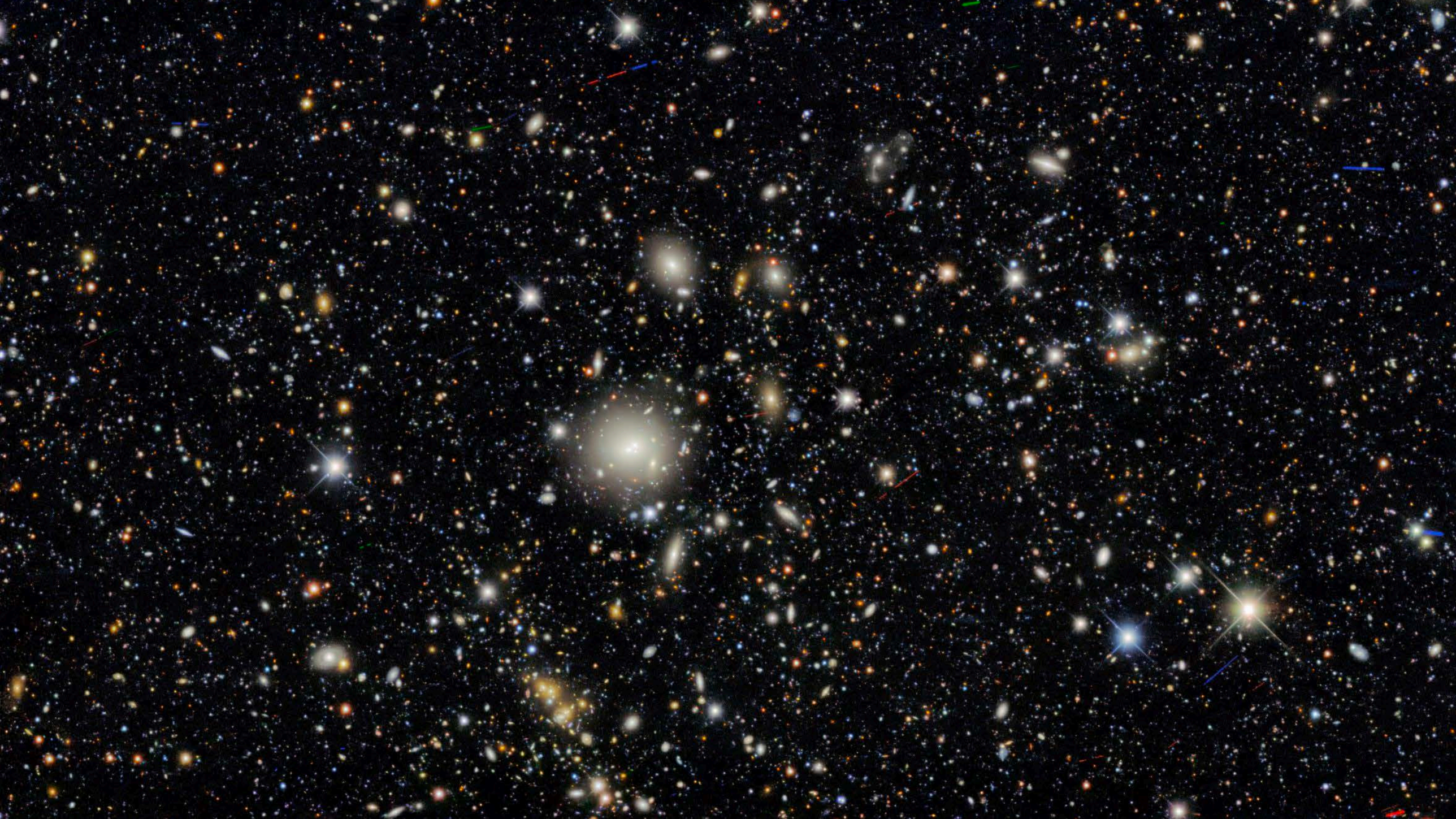
Outline

- Measuring the shapes of billions of galaxies to one part in ten thousand
- What we learned from precursor surveys
- Counting down to first light

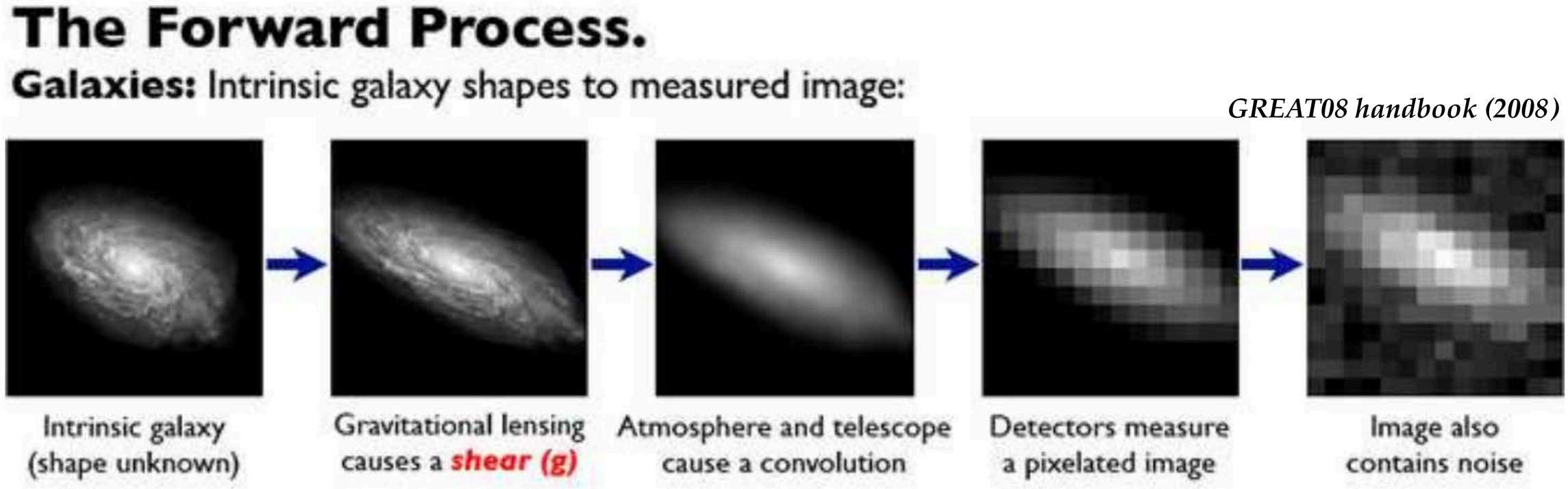
Measuring the shapes of billions of galaxies to one part in ten thousand



To zeroth order, weak lensing is pretty straightforward, what we want is to have as many galaxies as possible with good shape measurements. The Dark Energy Task Force told us if we do that we would get dark energy nailed.



Good shear (=shape) measurements



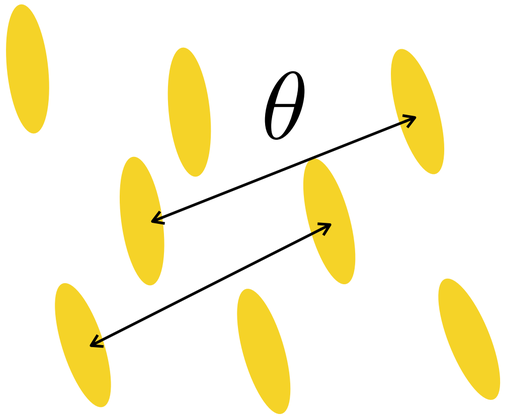
GREAT08 handbook (2008)

Shear to cosmology

Cosmic shear

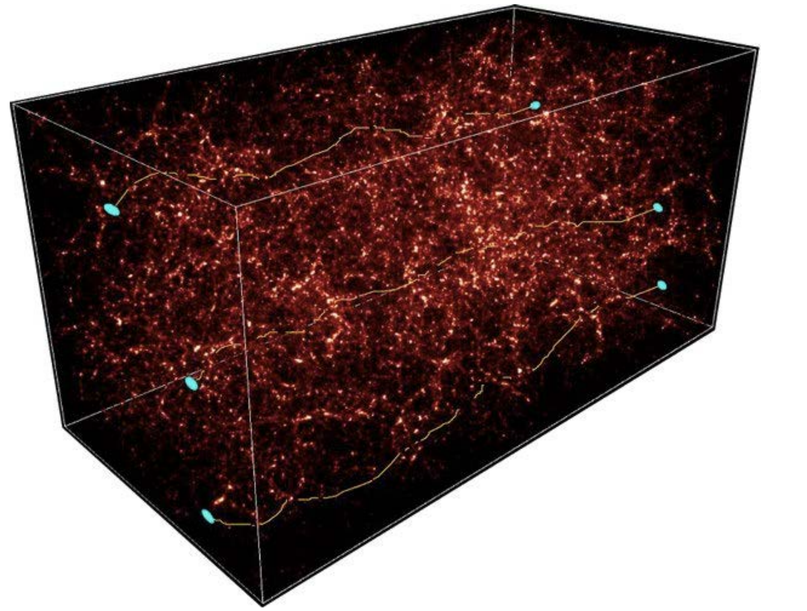
$$\xi_{\pm}(\theta) = \frac{\sum w^i w^j (\gamma_t^i(\theta_0)\gamma_t^j(\theta_0+\theta) \pm \gamma_\times^i(\theta_0)\gamma_\times^j(\theta_0+\theta))}{\sum w_i w_j}$$

$$= \frac{1}{2\pi}\int d\ell \ell J_{0/4}(\theta\ell) C_\gamma(\ell)$$



Lensing power spectrum

$$C_\gamma = \left(\frac{3H_0^2\Omega_m}{2c}\right)^2 \int_0^{\chi_H} d\chi \frac{W^2(\chi)}{a^2(\chi)} P_\delta\left(\frac{\ell}{\chi}, \chi\right)$$



Shear to cosmology

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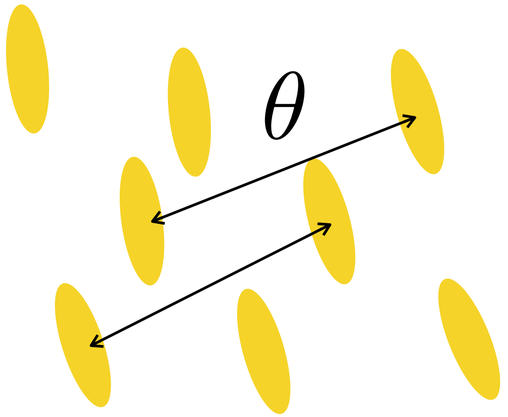
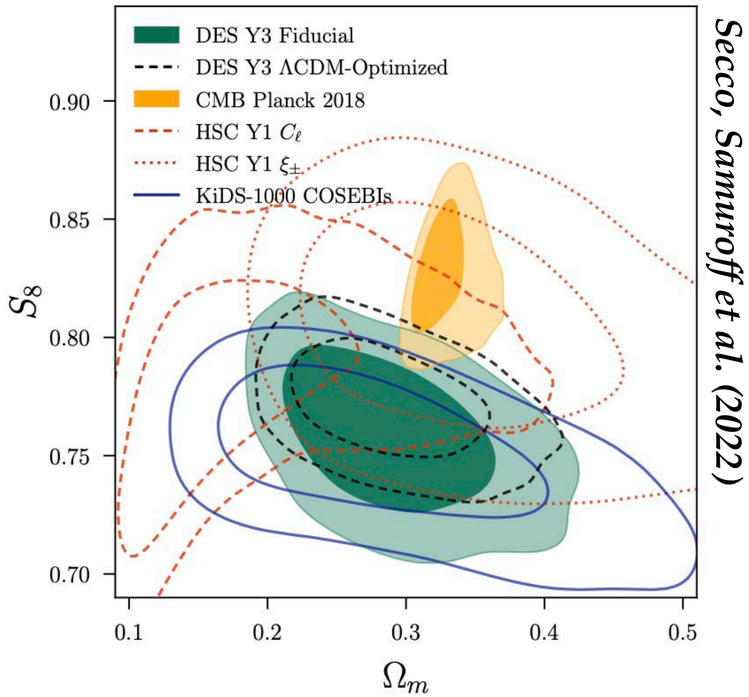


Lensing power spectrum —> cosmological parameters

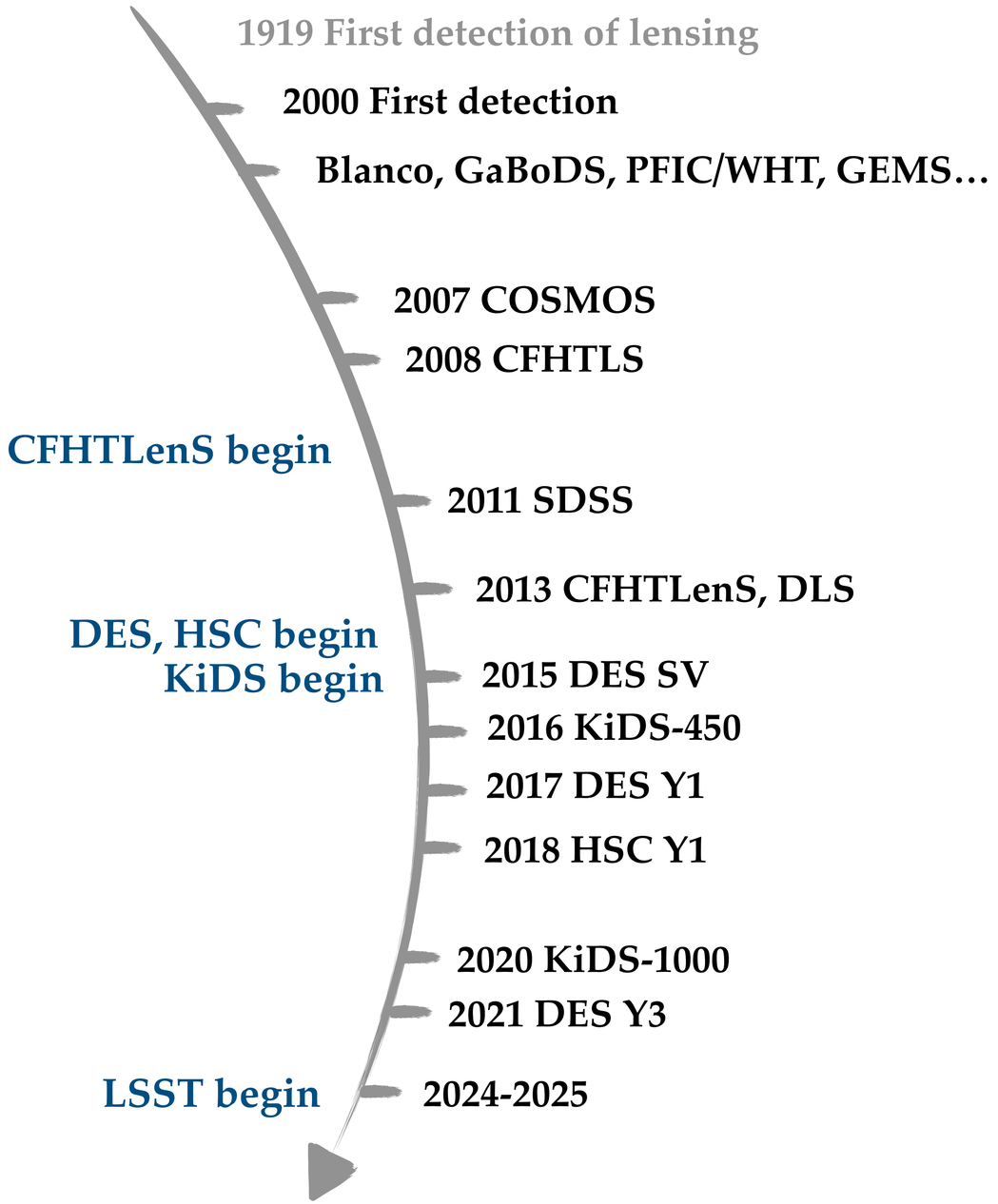
$$C_\gamma = \left(\frac{3H_0^2\Omega_m}{2c}\right)^2 \int_0^{\chi_H} d\chi \frac{W^2(\chi)}{a^2(\chi)} P_\delta\left(\frac{\ell}{\chi}, \chi\right)$$



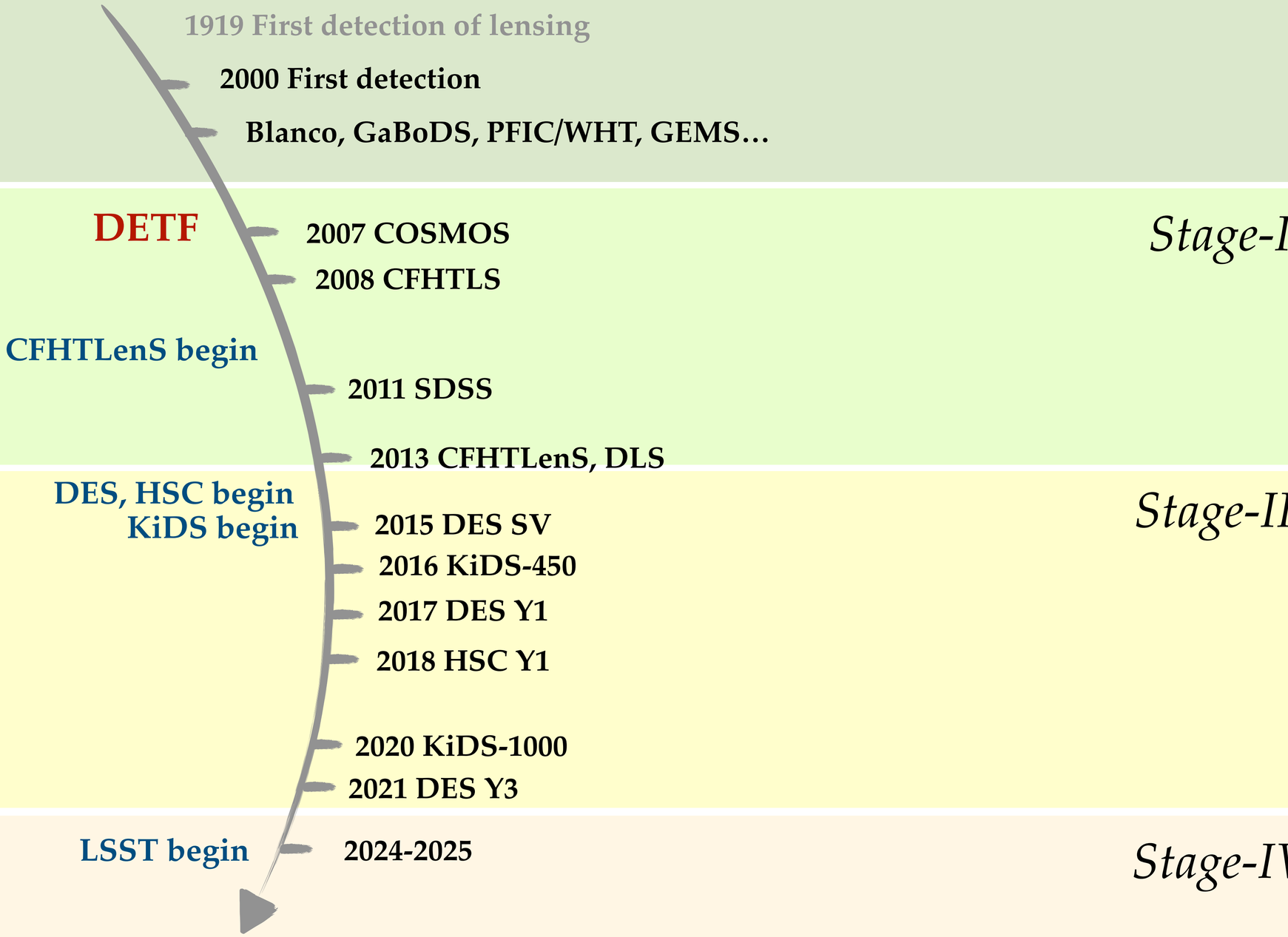
Secco, Samuroff et al. (2022)

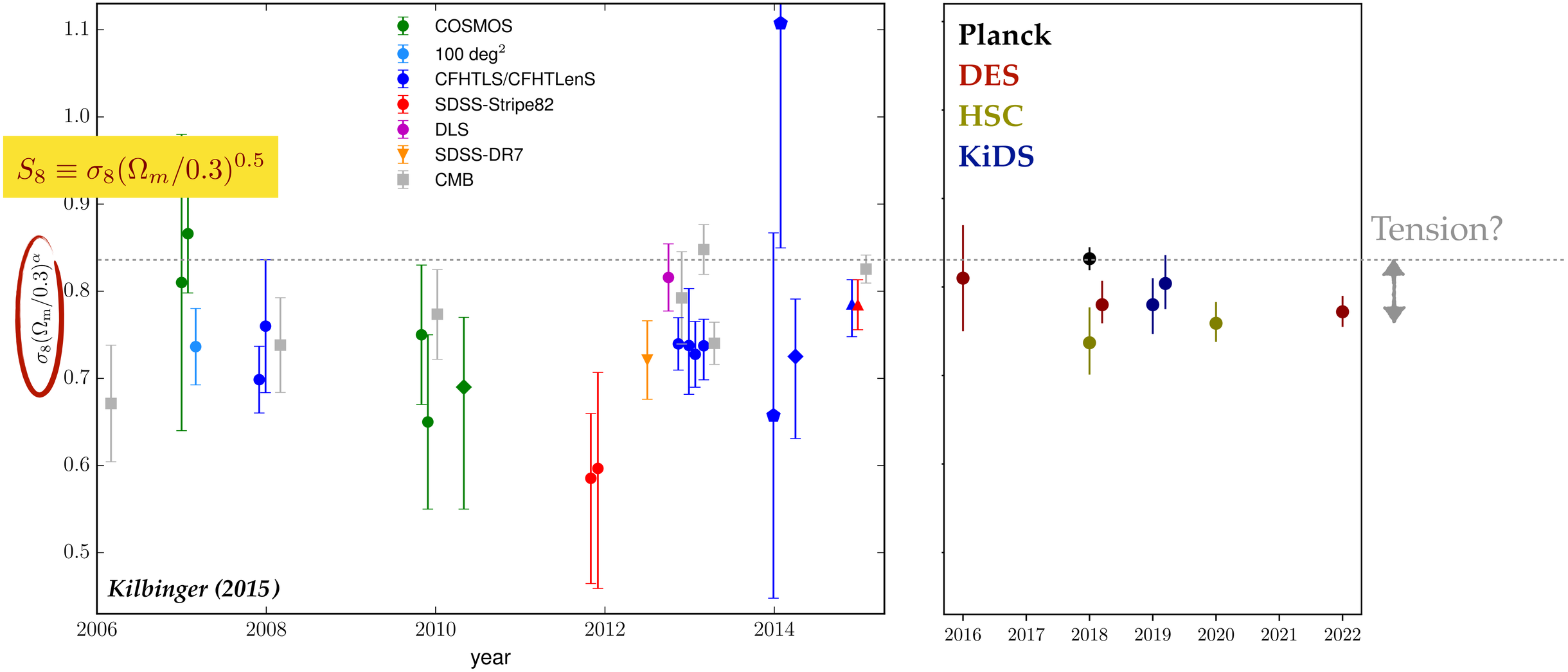
What we learned from precursor surveys

Cosmic shear timeline



Cosmic shear timeline




$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$
$\sigma_8(\Omega_m/0.3)^\alpha$
COSMOS
100 deg^2
CFHTLS/CFHTLenS
SDSS-Stripe82
DLS
SDSS-DR7
CMB
Kilbinger (2015)
year
Planck
DES
HSC
KiDS
Tension?

Cosmic shear timeline

1919 First detection of lensing

2000 First detection

Blanco, GaBoDS, PFIC/WHT, GEMS…

2007 COSMOS

2008 CFHTLS

CFHTLenS begin

2011 SDSS

2013 CFHTLenS, DLS

DES, HSC begin

KiDS begin

2015 DES SV

2016 KiDS-450

2017 DES Y1

2018 HSC Y1

2020 KiDS-1000

2021 DES Y3

LSST begin

2024-2025

What lensers worry about

getting more galaxies

shape measurement
(noise and modeling bias)
PSF modeling

shape measurement
(selection bias)
photometric redshift calibration
intrinsic alignment
baryons
blending
tensions

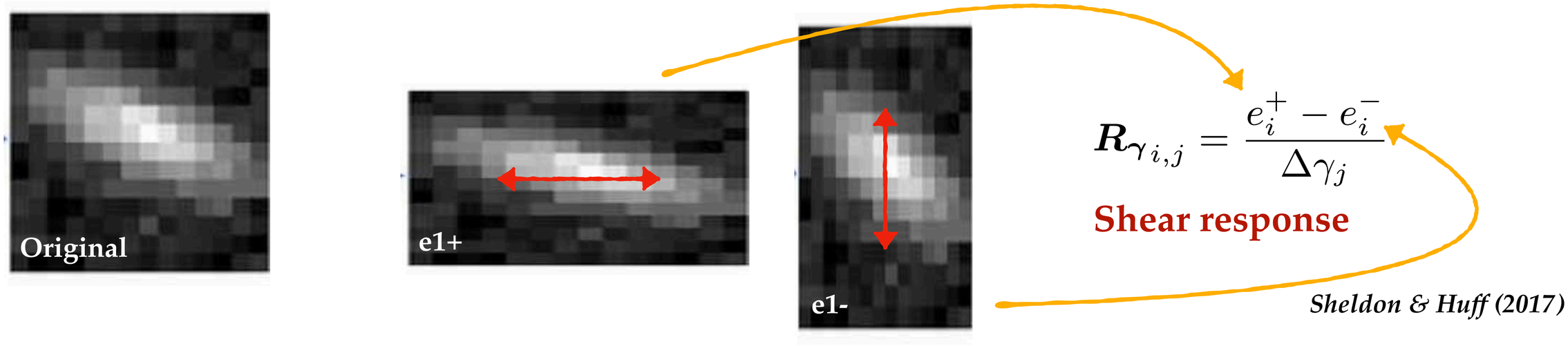
surprise!

MetaCalibration **and** MetaDetection

Unbiased estimation of shear is challenging due to the PSF and noise.

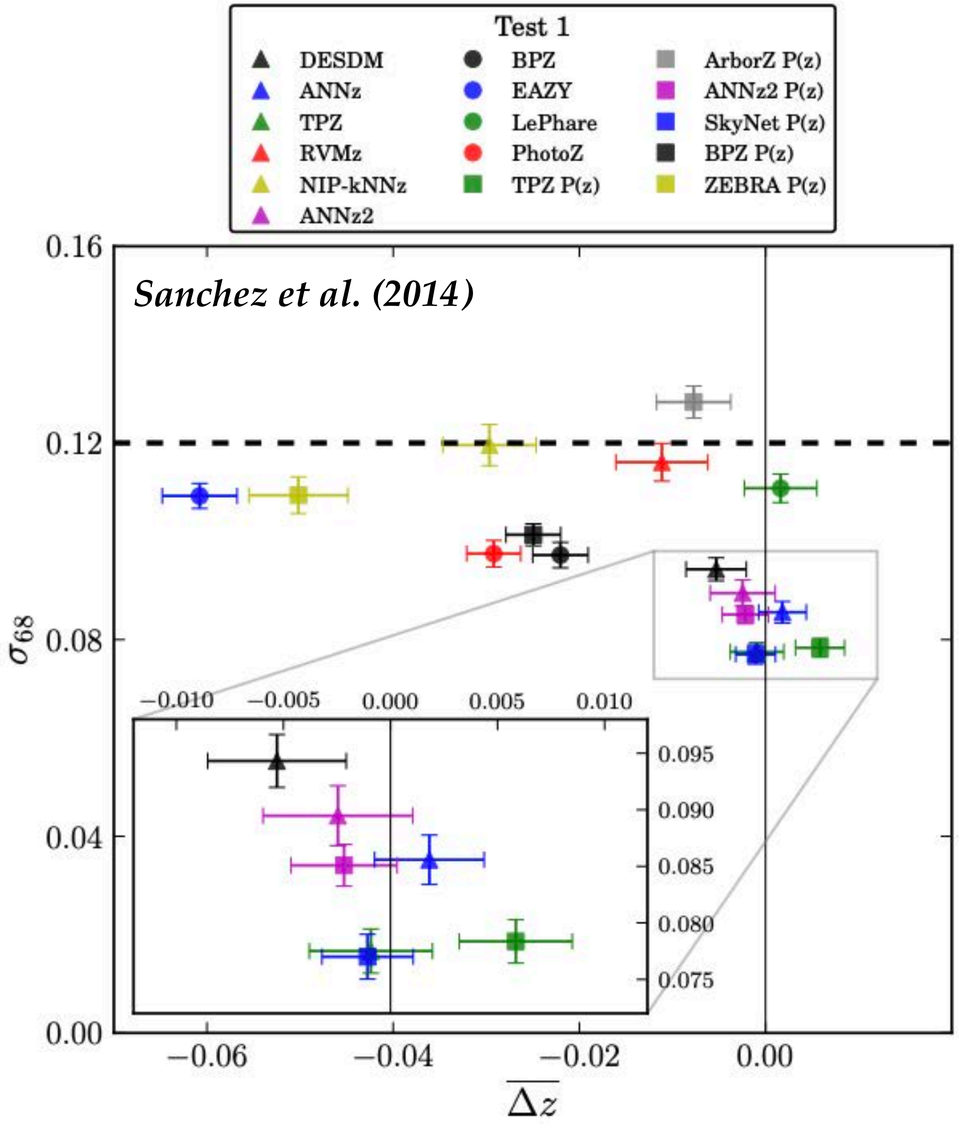
The community went through phases of different methods: direct moment-based, forward-fitting, simple method + calibration through sophisticated simulations…

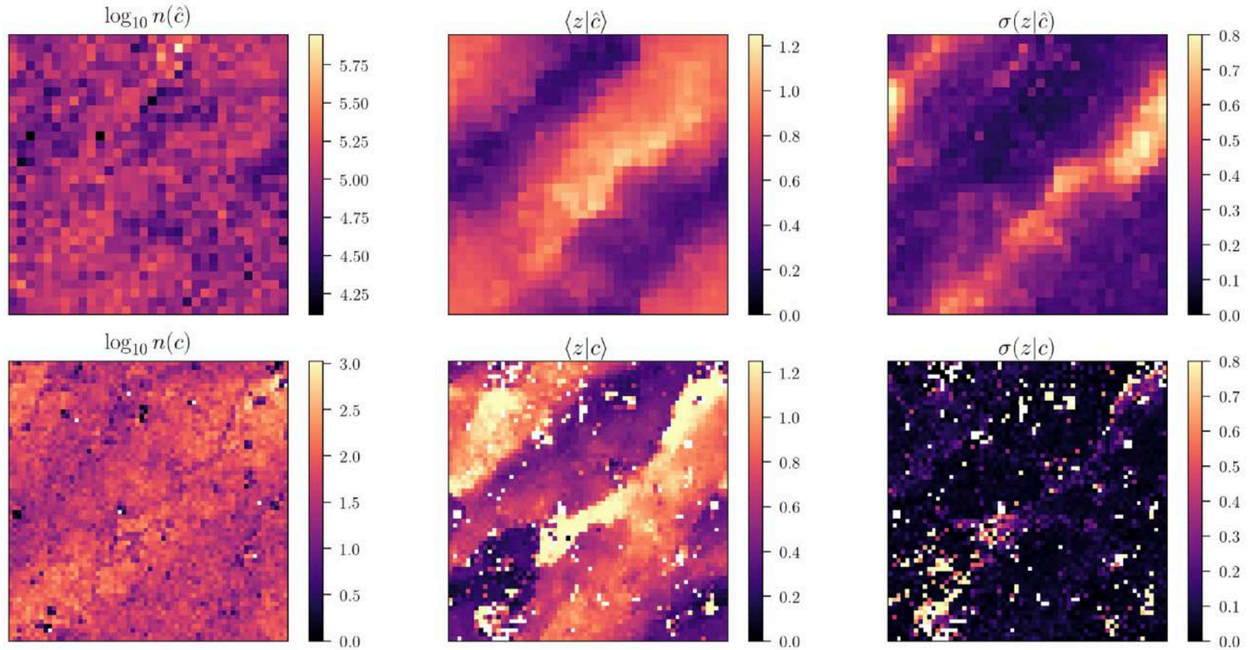
Using **directly the data** to understand the response of our shear estimator to cosmological shear.



Sheldon & Huff (2017)

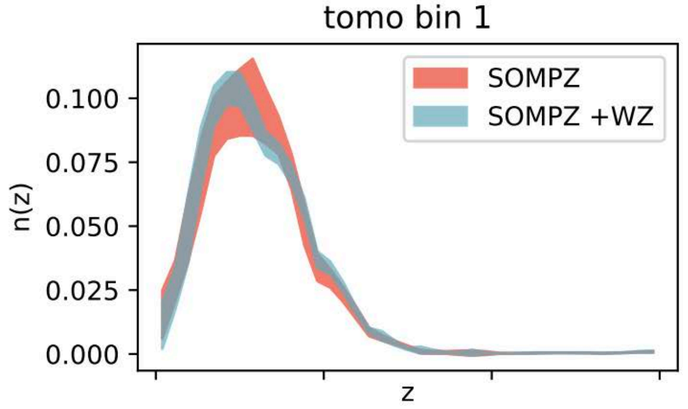
Photometric redshifts





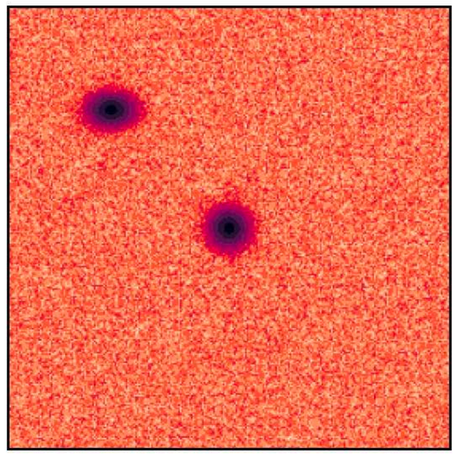
Myles et al. (2022)

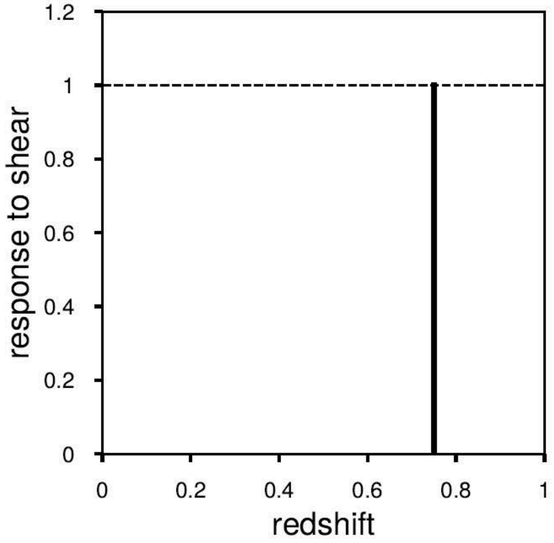
+

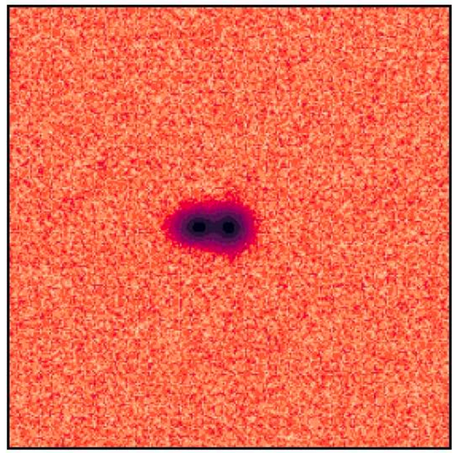


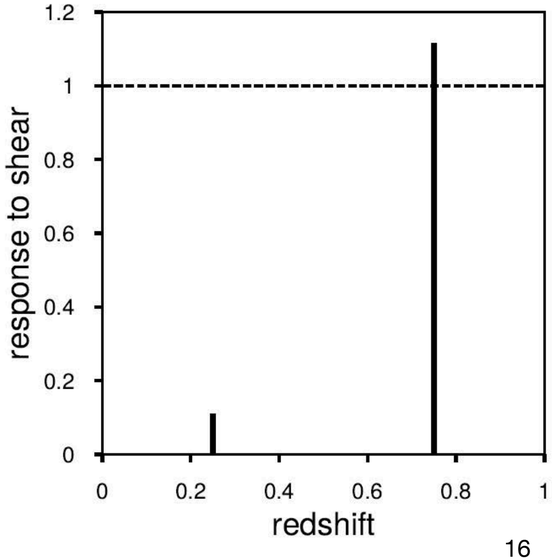
Gatti et al. (2022)

Blending couples shear and photo-z's

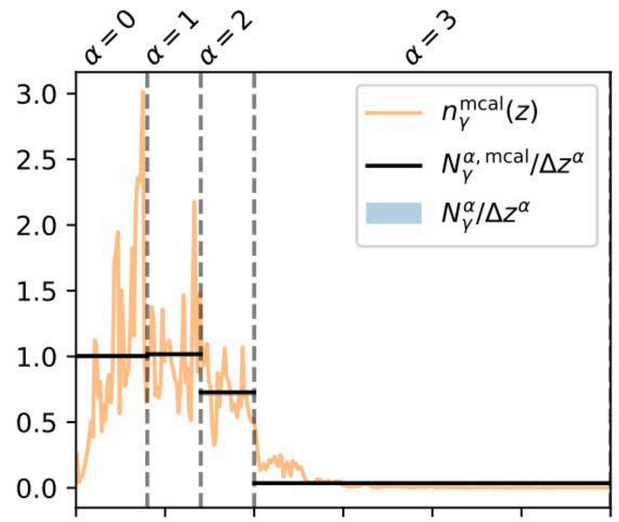


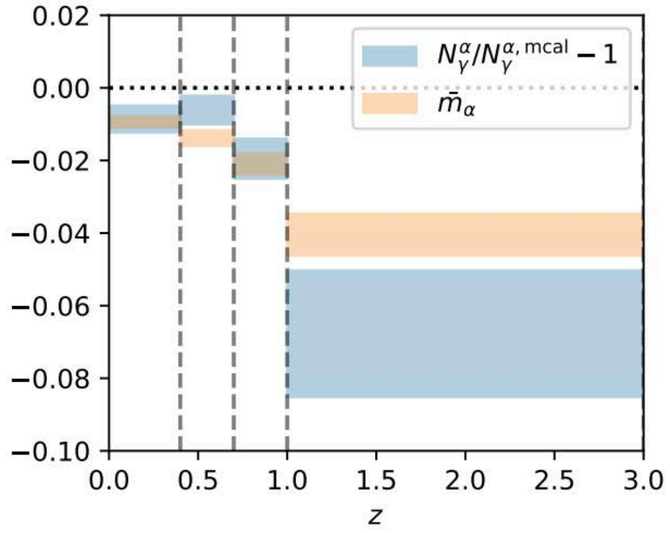






MacCrann et al. (2021)

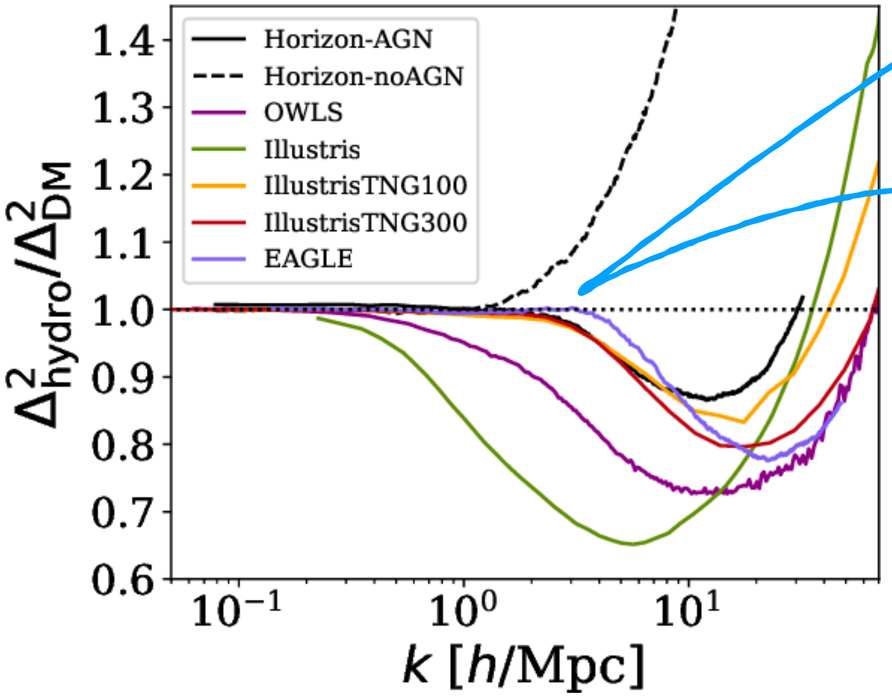




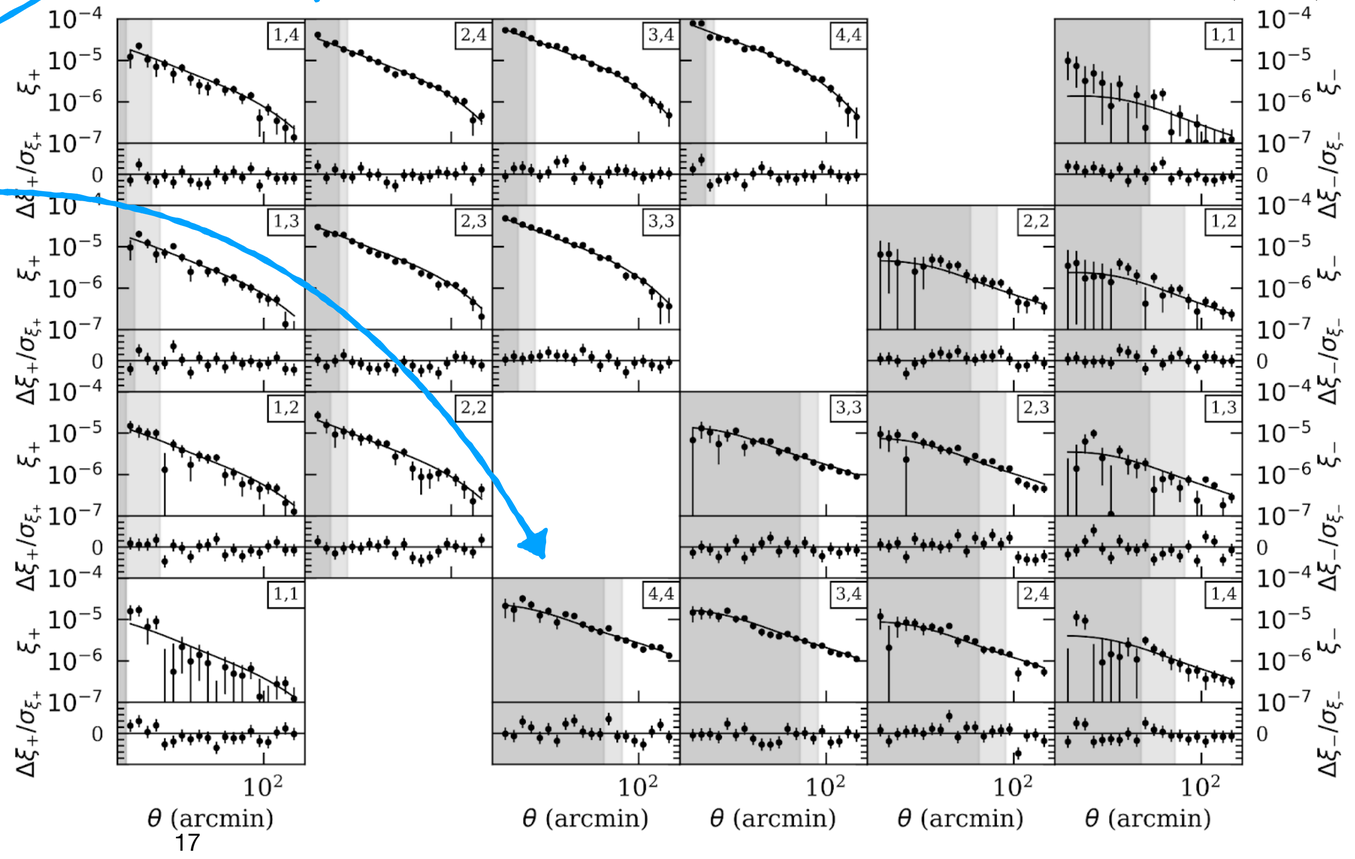
Baryonic feedback

Stars and AGNs heat and spew gas outside of the core of dark matter halos. This process alters the total matter distribution from an otherwise CDM-only universe.

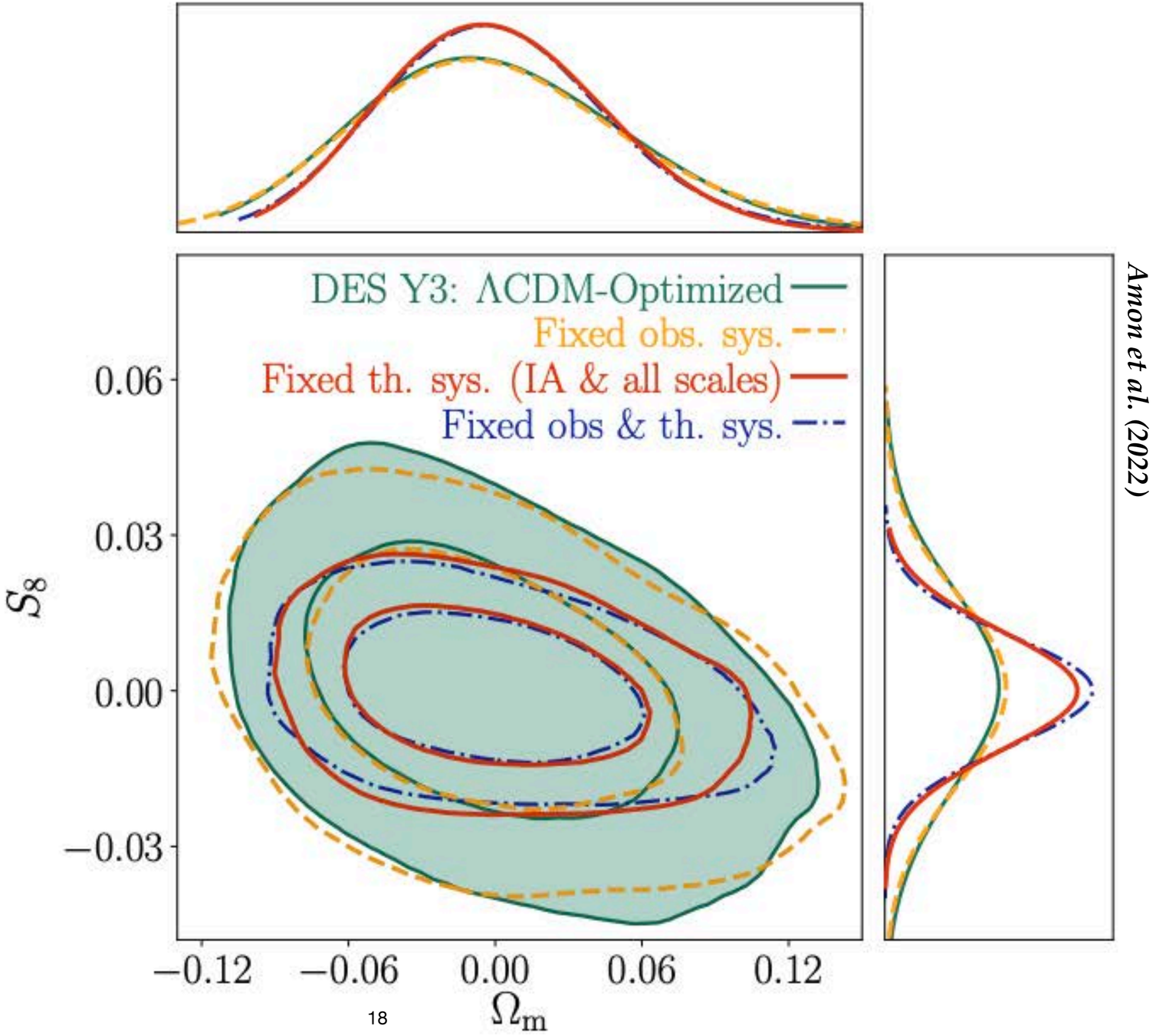
Chisari et al. (2017)



DES et al (2022)

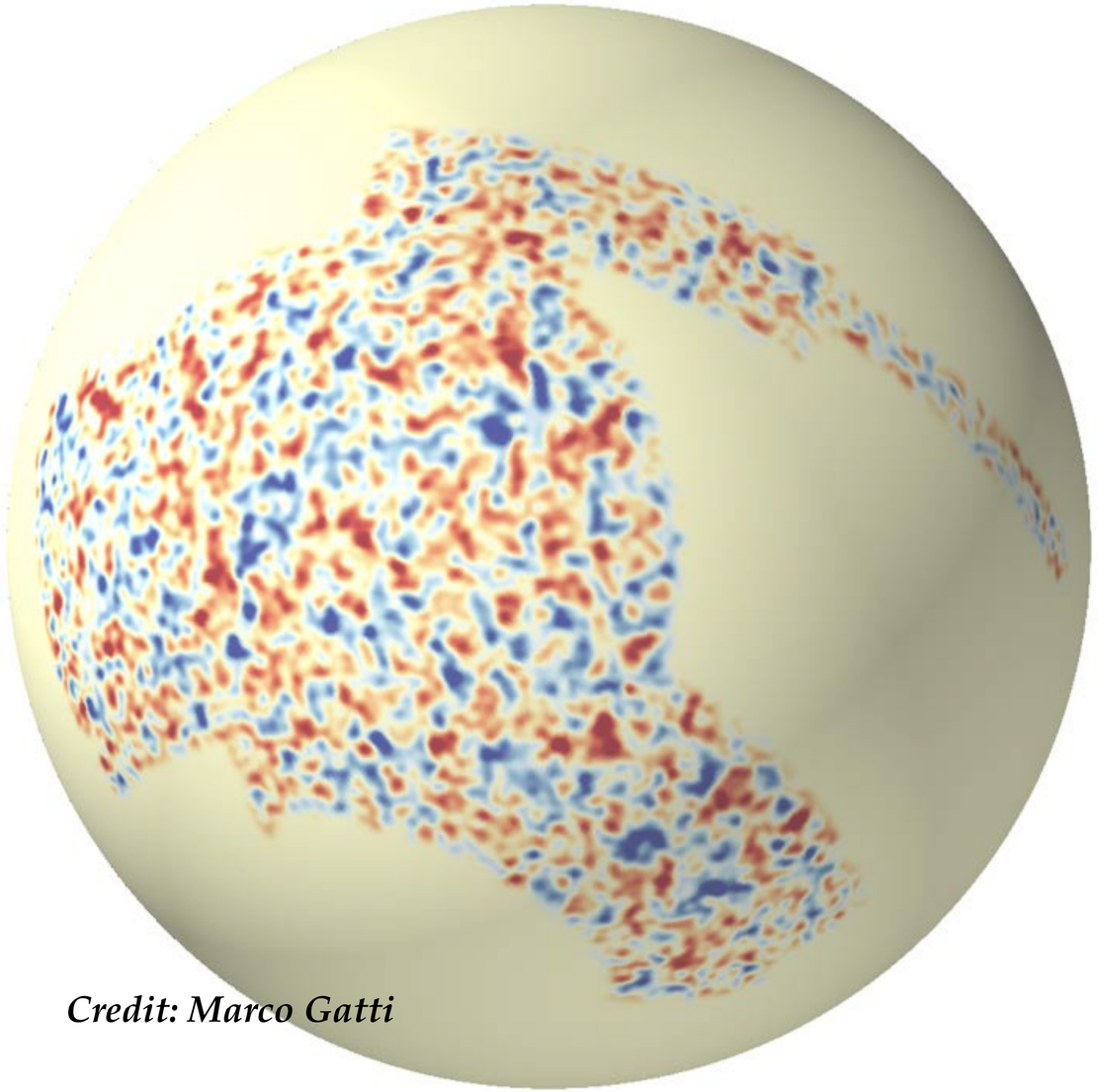


Systematics?
Statistics?

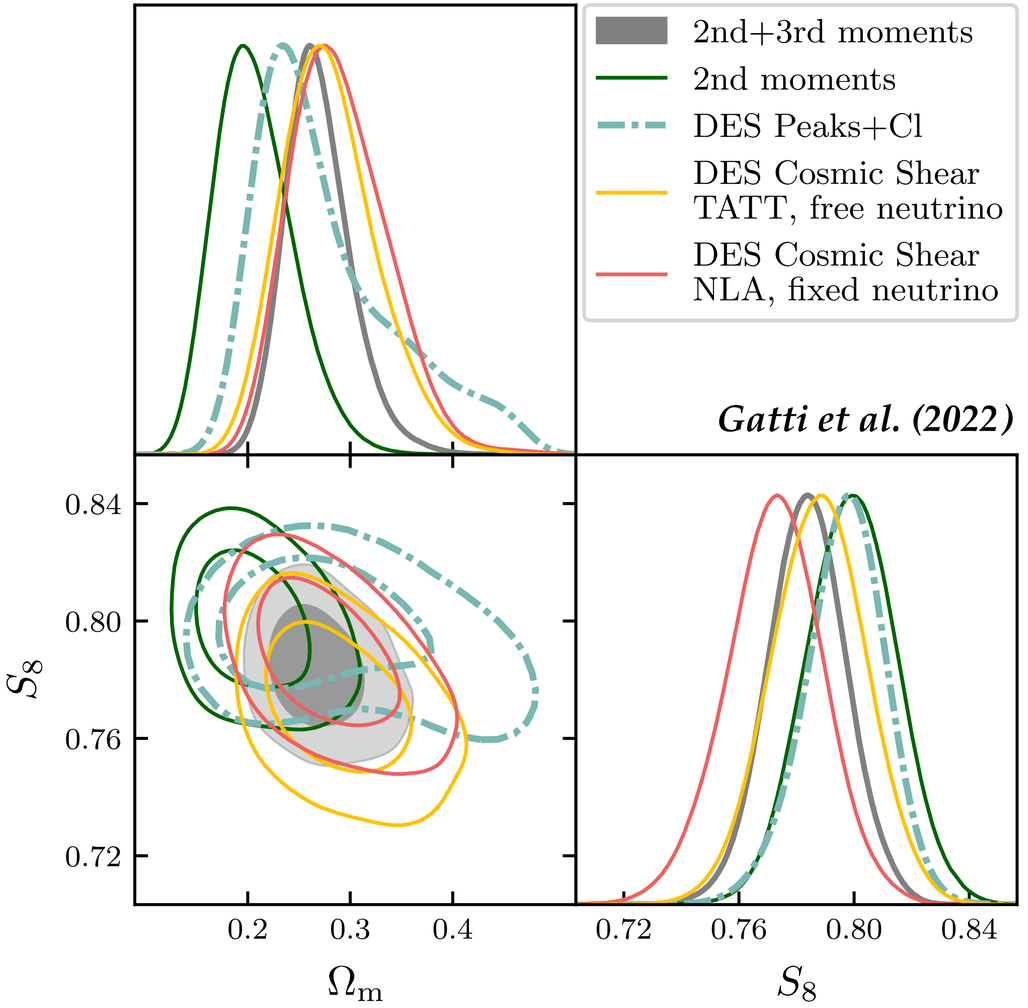


Amon et al. (2022)

And there's so many more ways to do cosmology



Credit: Marco Gatti

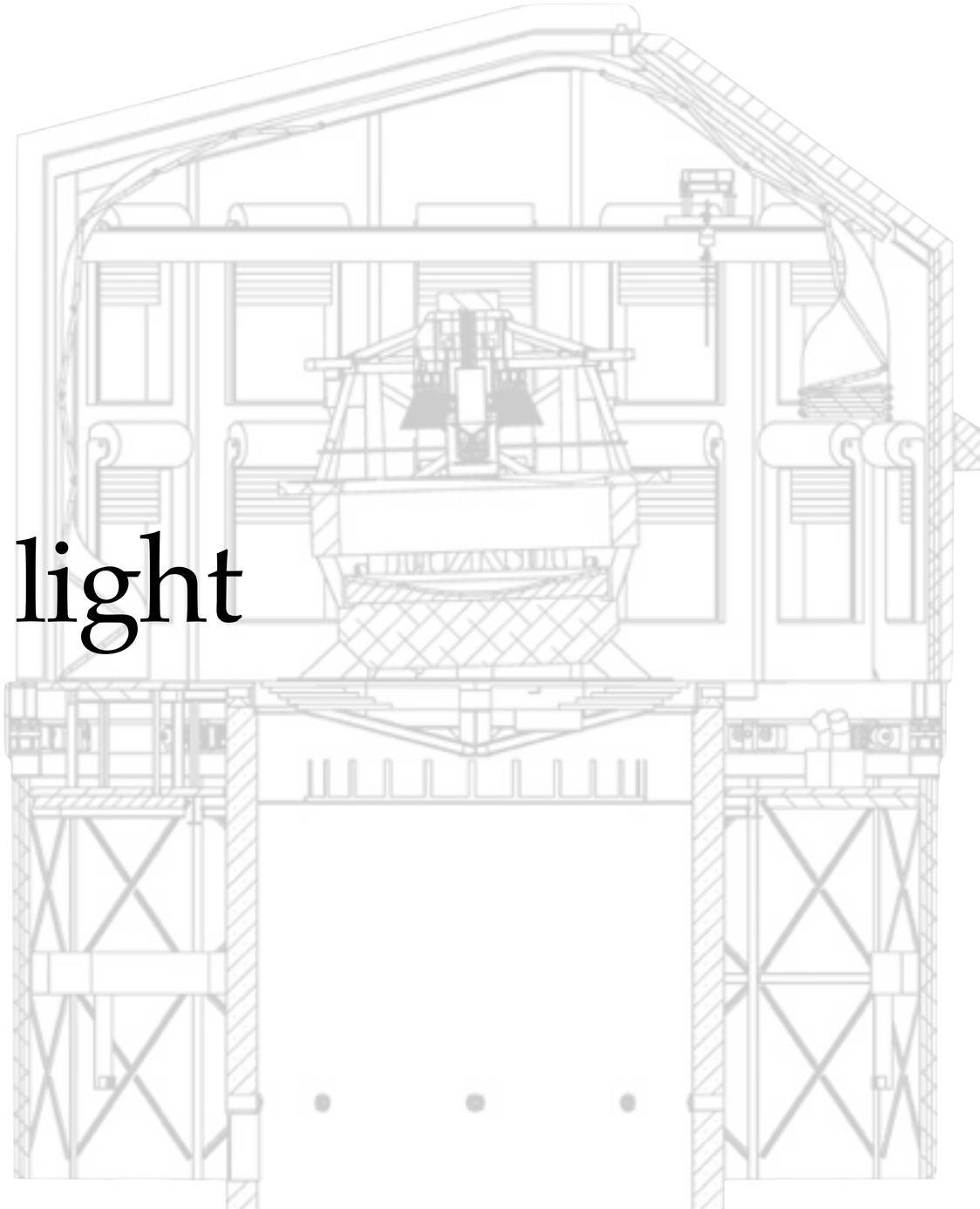


Gatti et al. (2022)

Some thoughts looking back at Stage-III

- We are learning a lot about the Universe and what we are measuring
- We are thinking about a whole new set of problems today than 10 years ago, the field has grown and matured significantly
- Every new dataset that is qualitatively different brings new sets of challenges, but once we soldier through the challenges we progress again
- A general survey goes way beyond what you expect it to do

Counting down to first light



Putting my DESC hat on

Credit: Judit Prat

I’m sure you all know this…

Rubin Operations Top Milestones

• **Jun 2023 - Sep 2023**	Complete Delivery of Data Preview 0.3 (DP0.3) (L1-RO-0180)	
• **Jul 2024 - Aug 2024**	System First Light (LSST-1520)	
• **Sep 2024 - Oct 2024**	Complete Delivery of Data Preview One (DP1) (L1-RO-0060)	(= System First Light + 2 months)
• **Nov 2024 - Feb 2025**	LSST Survey Start (L1-RO-0110)	(= Science Validation Surveys Complete + 1 day)
• **May 2025 - Aug 2025**	Complete Delivery of Data Preview Two (DP2) (L1-RO-0070)	(= Science Validation Surveys Complete + 6 months)
• **Nov 2025 - Apr 2026**	Complete Delivery of Data Release One (DR1) (L1-RO-0120)	(= LSST Survey Start + 12 months)
• **Nov 2026 - Apr 2027**	Complete Delivery of Data Release Two (DR2) (L1-RO-0130)	(= LSST Survey Start + 24 months)

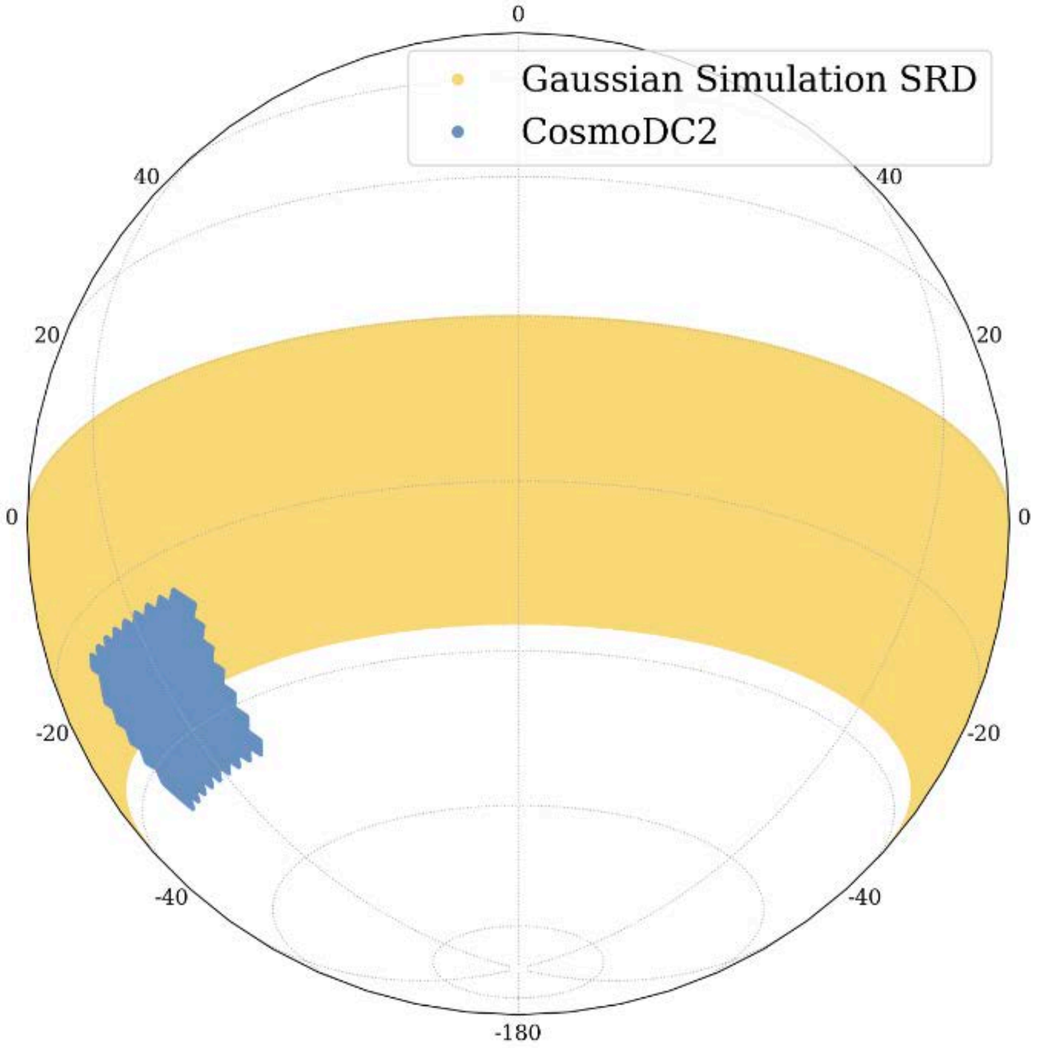
TABLE 7: Top milestones for the Early Science Program, as of January 2023.

Before data hits, we know it’s a good idea to be prepared, yet we also know that there will be surprises we cannot prepare for…

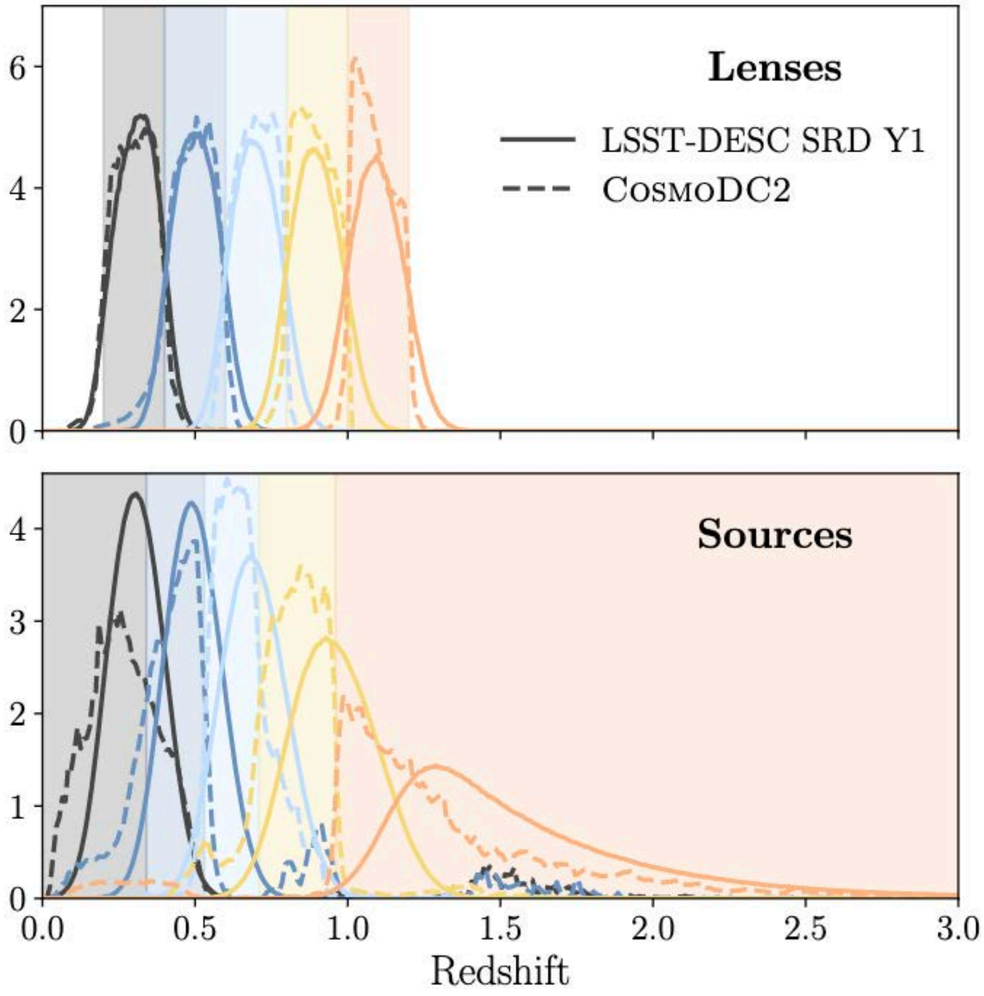
How do we prepare for LSST?

- Everything that is done in Stage-III surveys are almost automatically useful! As long as we synthesize what we've learned and properly transform the knowledge.
- Simulations are great cause we know the truth.
- Reanalysis of precursor data with LSST software.
- Team-building — in the end people do the work, and that is by far the most important thing.

Validating pipelineas on simulations

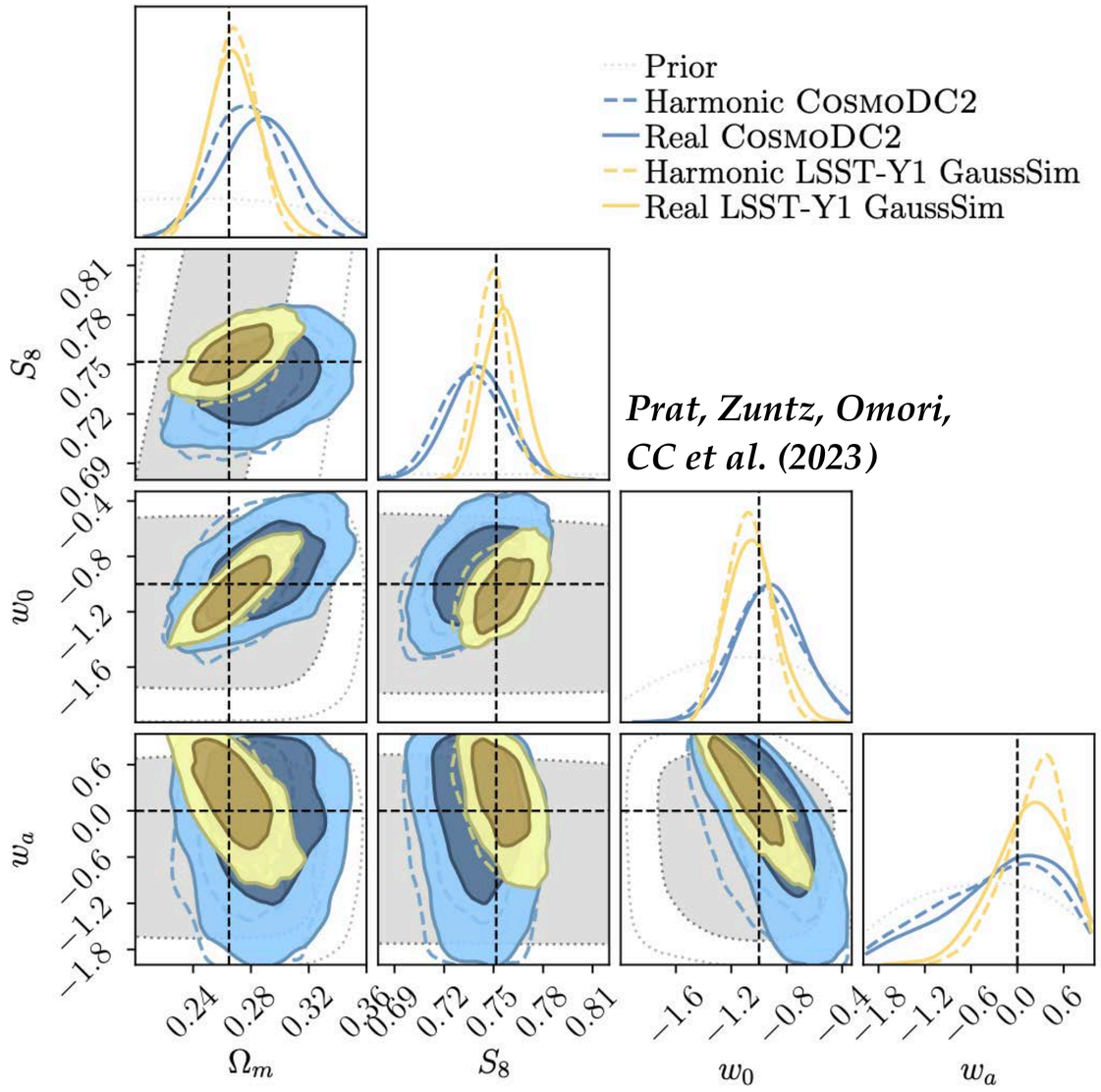


Prat, Zuntz, Omori, CC et al. (2023)



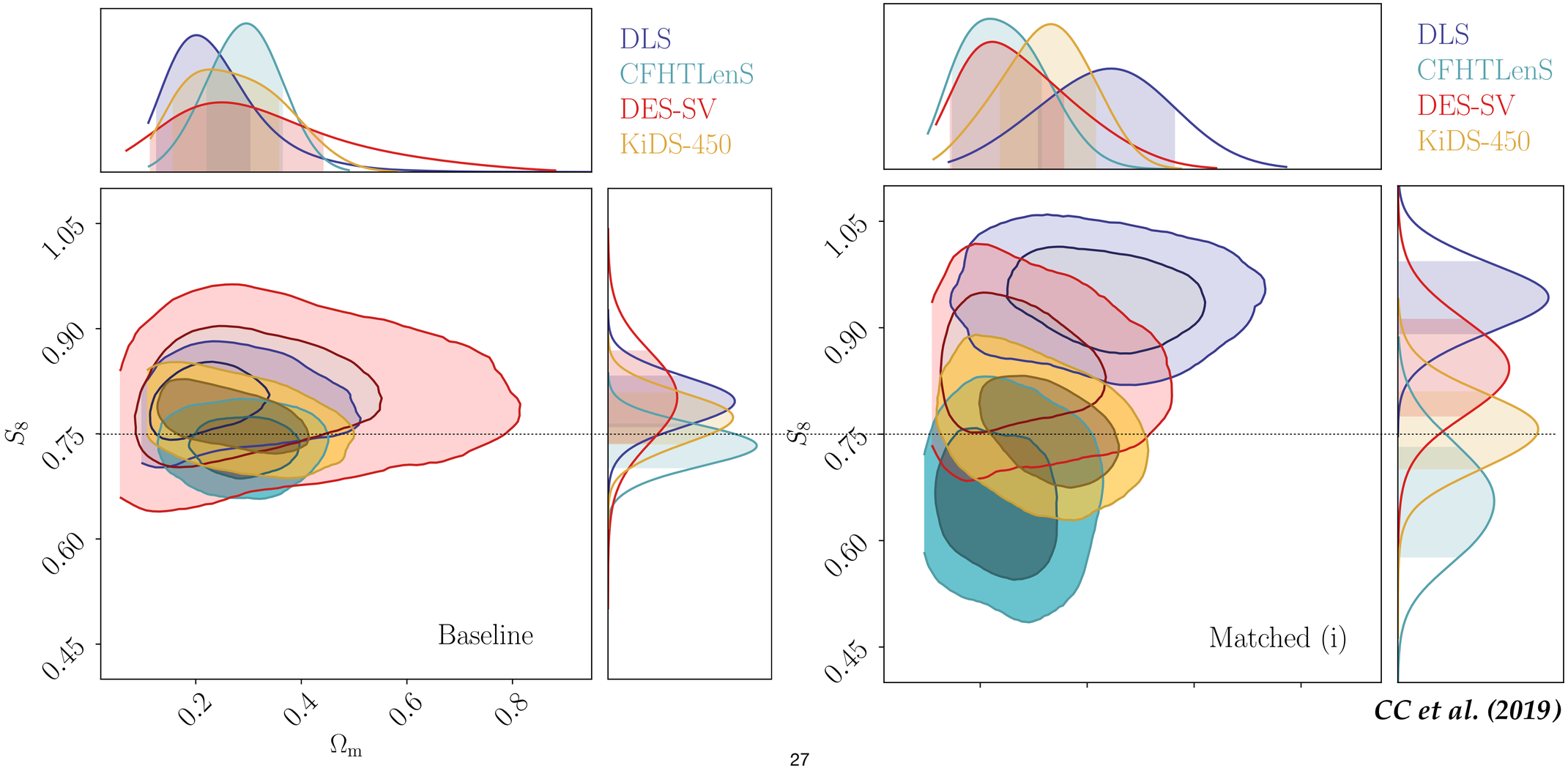
Validating pipelineas on simulations

- There exist a basic pipeline to perform large-scale structure catalog —> cosmology analysis to the precision required by Y1 LSST.
- There is still *a lot* to do to bring this pipeline to Stage-III level, but we will get there.



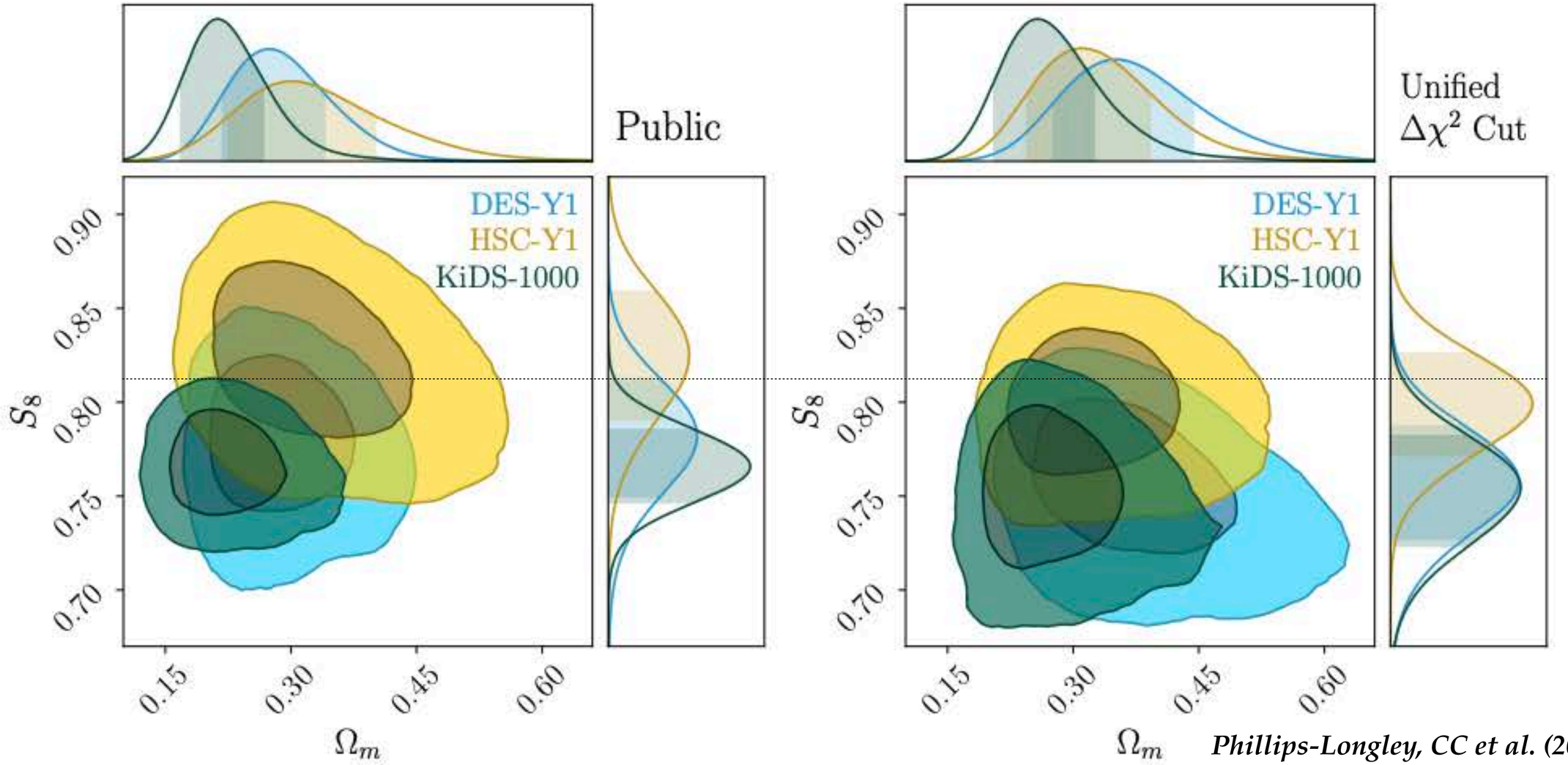
Prat, Zuntz, Omori, CC et al. (2023)

Cosmic shear reanalysis (~Stage-II)



CC et al. (2019)

Cosmic shear reanalysis (~Stage-III)



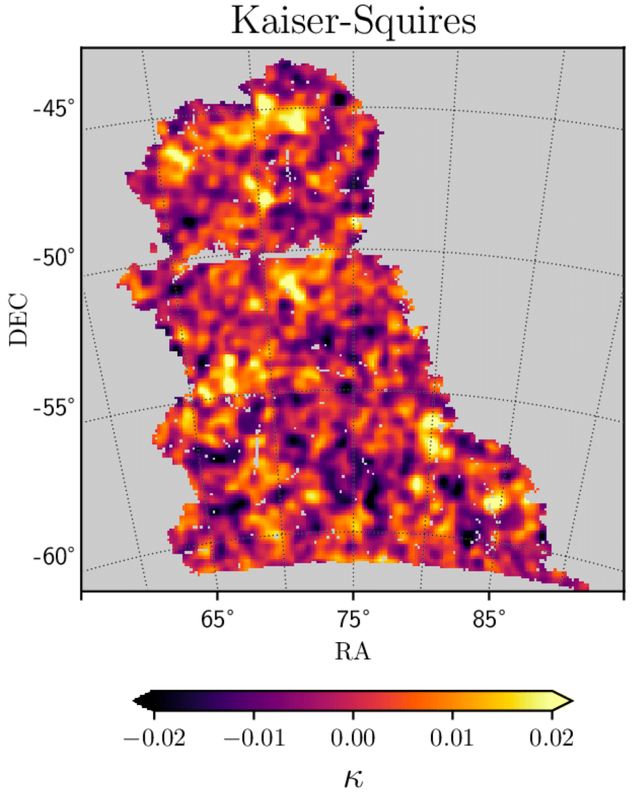
Phillips-Longley, CC et al. (2022)

The STatic Analysis Roundtable (STAR)

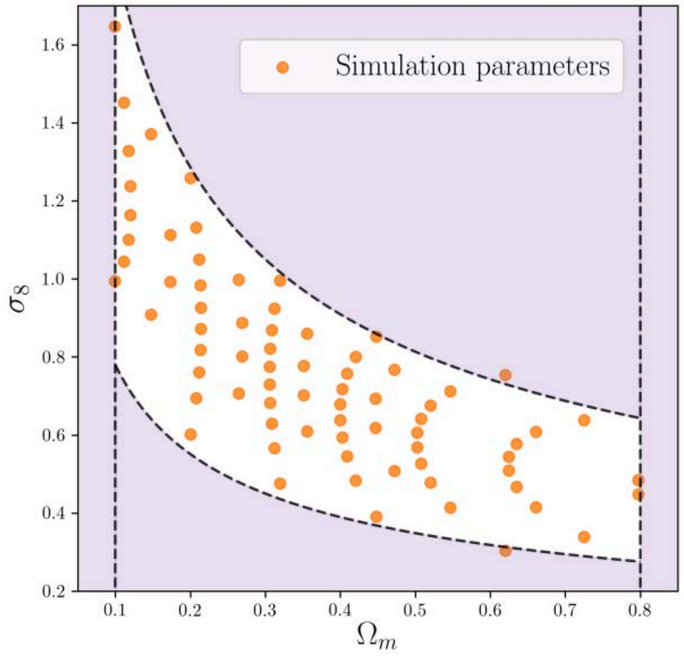
An initiative to slowly start building a *team* for the LSST Y1 static analysis.

Starting from Prat et al. (2023), we want to gradually bring each of elements to the maturity level of Stage-III: shear catalogs, photo-z's, systematics tests, modeling etc.

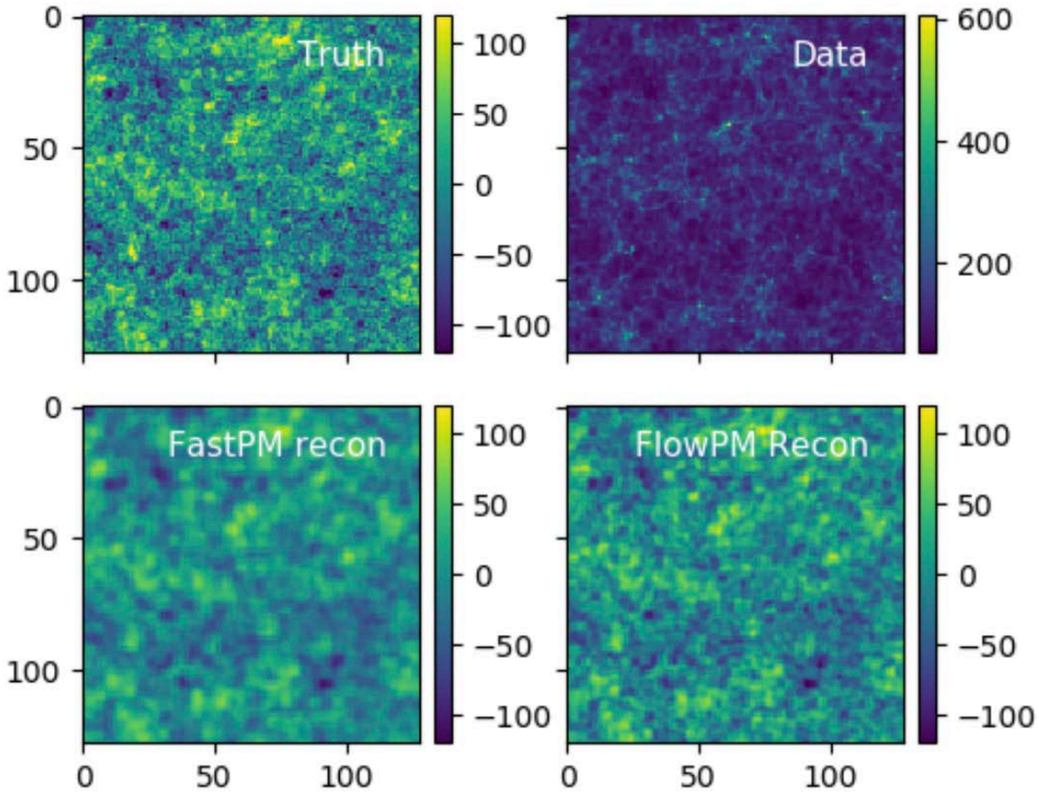
It could also be that we will be doing something completely different in 5 years!



Jeffrey et al. (2020)



Modi et al. (2020)



Thanks Steve — this has been super fun!

- There are things you learn from your PhD advisor that is much beyond the technicalities of the science topic. A lot of it you don't really realize at the moment.
- From Steve, I've been lucky to see
  - How one sustains a vision for the future
  - How an effort as important as Rubin is built over many 10s of years
  - How to lead a large group, and still manage to take care of your grad students
  - How to get things done
- If Stage-III were any guide, we are about to enter an explosion of new things to both worry about and get excited with Rubin data — let's get this thing started!

Questions?